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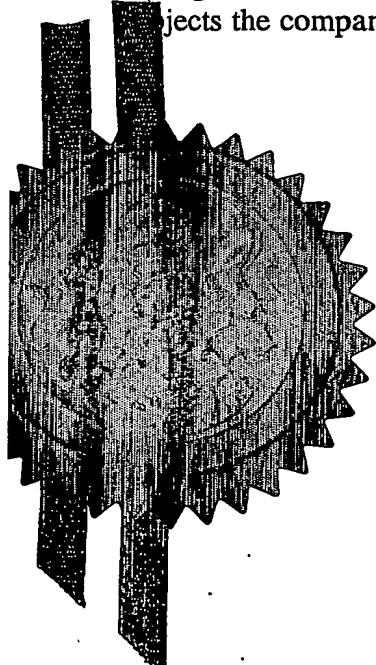
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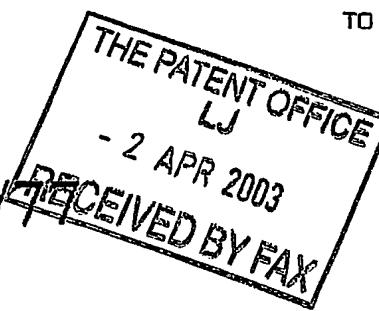
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Patents Form 1



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Request for grant of a patent

02APR03 E797190-1 D02846
P01/7700 0.00-0307606.4

1. Your Reference	APB/CAL/Y767		
2. Application number	0307606.4	F 2 APR 2003	
3. Full name, address and postcode of the or each Applicant Country/state of incorporation (if applicable)	Victrex Manufacturing Limited Victrex Technology Centre Hillhouse International THORNTON CLEVELEY'S Lancashire FY5 4QD <i>6510887003</i> <i>TE</i> Incorporated in: UK		
4. Title of the invention	ION-CONDUCTING POLYMERIC MATERIALS		
5. Name of agent Address for service in the UK to which all correspondence should be sent	APPLEYARD LEES 15 CLARE ROAD HALIFAX HX1 2HY		
Patents ADP number	190001		
6. Priority claimed to:	Country	Application number	Date of filing
7. Divisional status claimed from:	Number of parent application		Date of filing
8. Is a statement of inventorship and of right to grant a patent required in support of this application?	YES		

Patents Form 1/77

Page 2/2

9. Enter the number of sheets for any of the following items you are filing with this form. Do not count copies of the same document

Continuation sheets of this form

Description 30

Claim(s)

Abstract

Drawing(s) 1 only

10. If you are also filing any of the following, state how many against each item

Priority documents

Translation of priority documents

Statement of inventorship and right to grant a patent (PF 7/77)

Request for a preliminary examination and search (PF 9/77)

Request for substantive examination (PF 10/77)

Any other documents (please specify)

11.

We request the grant of a patent on the basis of this application.
Signature _____ Date _____

APPLEYARD LEES

02 April 2003

12. Contact

Anthony P Brierley 01422 330110

Case 11/1

ION-CONDUCTING POLYMERIC MATERIALS

This invention relates to ion-conducting polymeric materials and particularly, although not exclusively, 5 relates to a method of preparing a formulation of an ion-conducting polymeric material and such a formulation per se. Preferred embodiments relate to the use of formulations prepared in the manufacture of coatings or films of ion-conducting polymeric materials.

10

One type of polymer electrolyte membrane fuel cell (PEMFC), shown schematically in Figure 1 of the accompanying diagrammatic drawings, may comprise a thin sheet 2 of a hydrogen-ion conducting Polymer Electrolyte Membrane (PEM) 15 sandwiched on both sides by a layer 4 of platinum catalyst and an electrode 6. The layers 2, 4, 6 make up a Membrane Electrode Assembly (MEA) of less than 1mm thickness.

In a PEMFC, hydrogen is introduced at the anode (fuel 20 electrode) which results in the following electrochemical reaction:



25 The hydrogen ions migrate through the conducting PEM to the cathode. Simultaneously, an oxidant is introduced at the cathode (oxidant electrode) where the following electrochemical reaction takes place:



Case 11/1

Thus, electrons and protons are consumed to produce water and heat. Connecting the two electrodes through an external circuit causes an electrical current to flow in the circuit and withdraw electrical power from the cell.

5

Preferred ion-conducting polymeric materials for use as components of polymer electrolyte membranes in fuel cells have high conductivity (low EW, or high ion-exchange capacities), optimum water uptake for good conductivity and mechanical properties and solubility in solvents which can be used to cast the membranes.

10 Examples of known ion-conducting polymeric materials are described in US 5985477 (Sumitomo) and US 5906716 (Hoechst). The polyaryletherketones and/or sulphones described are dissolved in a solvent, usually N-methylpyrrolidone (NMP), and are then cast to prepare membranes.

15 20 Whilst NMP is a very good solvent for casting membranes from a wide range of materials, membranes cast from NMP (especially polymer electrolyte membranes of fuel cells) can have defects and/or exhibit problems in downstream process steps. Furthermore, it is preferred for 25 environmental and safety reasons to minimise the amounts of organic solvents used in chemical processes.

30 It is an object of the present invention to address problems associated with the preparation and/or use of formulations of ion-conducting polymeric materials.

According to a first aspect of the present invention, there is provided a method of preparing a formulation

Case 11/1

comprising an ion-conducting polymeric material, the method comprising:

(a) selecting an ion-conducting polymeric material of a type which includes:

- (i) phenyl moieties;
- (ii) carbonyl and/or sulphone moieties; and
- (iii) ether and/or thioether moieties;

(b) selecting a solvent mixture comprising water and a first organic solvent in which mixture said ion-conducting polymeric material can be dissolved and/or dispersed;

(c) dissolving and/or dispersing said ion-conducting polymeric material in said solvent mixture;

(d) removing greater than 80% of the total amount of said first organic solvent in said solvent mixture, thereby to leave a formulation comprising said ion-conducting polymeric material dissolved and/or dispersed in a solvent formulation comprising a major amount of water.

Surprisingly, it has been found that a stable solution and/or dispersion of the polymeric material in a substantial amount of water can be prepared in the method which solution/dispersion would not generally be preparable by simply attempting to dissolve/disperse the polymeric material in a solvent formulation comprising the same amount of water, without the use of steps (b) to (d) of the method.

Case 11/1

The formulations prepared in the method appear to the naked eye to be solutions; however, they are probably not true solutions but more likely are very fine dispersions of the ion-conducting polymeric material in the solvent 5 formulation.

Said first organic solvent selected in step (b) is preferably water miscible at 25°C. Said first organic solvent preferably has a boiling point of less than that 10 of water. The boiling point of the first organic solvent may be less than 95°C, suitably less than 90°C, preferably less than 85°C, more preferably less than 80°C, especially less than 75°C, at atmospheric pressure. The boiling point may be greater than 30°C, suitably greater than 15 40°C, preferably greater than 50°C, more preferably greater than 55°C at atmospheric pressure.

Said first organic solvent may have up to five, preferably up to four, carbon atoms. Preferably, said first organic 20 solvent has two to four carbon atoms. Said first organic solvent preferably includes an hydroxy, ether or carbonyl functional group. Preferably, said first organic solvent includes only one of said functional groups. Said first organic solvent preferably does not include any other 25 functional groups. Said first organic solvent preferably does not include any halogen atoms. Said first organic solvent is preferably saturated. Said solvent may be selected from alcohols, ethers (including cyclic ethers) and ketones, especially C₂₋₄ alcohols, ethers and ketones. 30 Especially preferred first organic solvents are acetone, methylethylketone, ethanol and tetrahydrofuran.

Case 11/1

Said solvent mixture selected in step (b) may include more than one organic solvent and each may be as described in any statement herein.

- 5 In one embodiment, said solvent mixture may include an optional second organic solvent. Said second organic solvent may have a boiling point which is greater than that of said first organic solvent so that said first organic solvent is preferentially removed in step (d) and,
10 preferably, less than 10 wt%, more preferably less than 5 wt%, especially less than 1 wt%, of said second organic solvent is removed in step (d). Said second organic solvent may have a boiling point at atmospheric pressure which is at least 20°C greater than the boiling point of
15 said first organic solvent. Said second organic solvent may be included to facilitate the preparation of articles, for example films, in accordance with the third aspect described hereinafter. Said second organic solvent may act as a coalescing agent during film formation. However,
20 it is preferred for said second organic solvent to be included (if included at all) after step (d). Examples of second solvents are N-methylpyrrolidene and glycols such as ethylene glycol.
- 25 The ratio of the wt% of water to the wt% of said first organic solvent (preferably to the wt% of the total amount of organic solvent(s) in the mixture) is suitably in the range 0.25 to 2.5, preferably in the range 0.4 to 2.3 and, more preferably, in the range 0.5 to 1.5.
30 Suitably, said solvent mixture of step (c) includes at least 1 wt%, preferably at least 3 wt%, more preferably at least 7 wt%, especially at least 9 wt% of said ion-

Case 11/1

conducting polymeric material. Said solvent mixture may include less than 20 wt%, preferably less than 15 wt%, especially less than 12 wt% of said ion-conducting polymeric material.

5

Step (c) of the method is preferably carried out at a temperature which is less than the boiling point of the solvent mixture. Thus, step (c) preferably comprises dissolving and/or dispersing said ion-conducting polymeric material in said solvent mixture under conditions at which said solvent mixture is not boiling. Suitably, step (c) is carried out at ambient temperature (eg 20°C) or above and at less than the boiling point of said solvent mixture.

15

Step (d) suitably includes removing greater than 85%, preferably greater than 90%, more preferably greater than 95 wt%, especially greater than 99 wt% of said first organic solvent in step (d). Preferably, substantially 20 the entirety of said first organic solvent is removed in step (d).

Said first organic solvent is preferably evaporated off in step (d), suitably under a pressure of less than 25 atmospheric pressure. After removal of the first organic solvent, the solvent formulation which includes a major amount of water suitably includes at least 10 wt%, preferably at least 14 wt%, more preferably at least 18 wt% of said ion-conducting polymeric material in said 30 solvent formulation. The solvent formulation may include less than 30 wt% or less than 25 wt% of said ion-conducting polymeric material. However, a solvent formulation which is more concentrated in said ion-

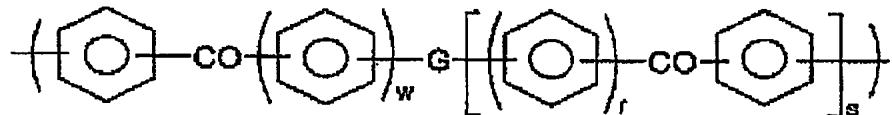
Case 11/1

conducting polymeric material may be prepared by removing, for example evaporating, some of the water in the solvent formulation which includes a major amount of water. In this event, said solvent formulation which includes a 5 major amount of water may include at least 30 wt%, at least 40 wt% or even 50 wt% of said ion-conducting polymeric material.

Said ion-conducting polymeric material may include
10 a moiety of formula

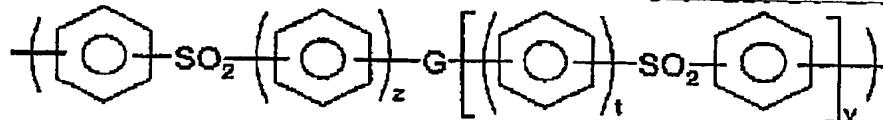


and/or a moiety of formula
15



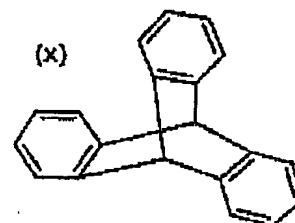
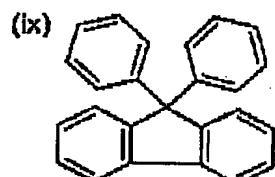
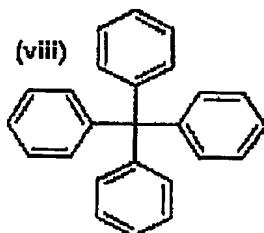
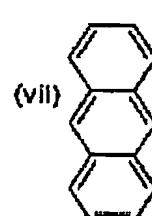
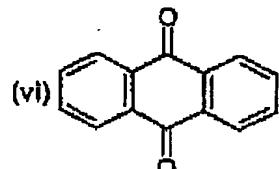
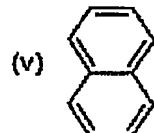
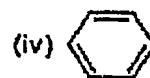
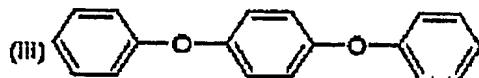
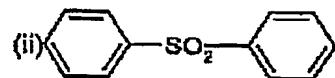
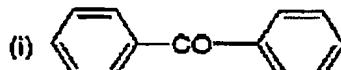
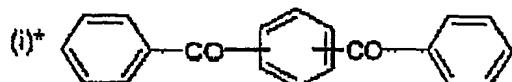
II

and/or a moiety of formula
20



III

wherein at least some of the units I, II and/or III are functionalised to provide ion-exchange sites, wherein the phenyl moieties in units I, II, and III are independently 5 optionally substituted and optionally cross-linked; and wherein m, r, s, t, v, w and z independently represent zero or a positive integer, E and E' independently represent an oxygen or a sulphur atom or a direct link, G represents an oxygen or sulphur atom, a direct link or a -O-Ph-O- moiety 10 where Ph represents a phenyl group and Ar is selected from one of the following moieties (i)* or (i) to (x) which is bonded via one or more of its phenyl moieties to adjacent moieties



Unless otherwise stated in this specification, a phenyl moiety may have 1,4- or 1,3-, especially 1,4-, linkages to 5 moieties to which it is bonded.

In (i)*, the middle phenyl may be 1,4- or 1,3- substituted.

Suitably, to provide said ion exchange sites, said 10 polymeric material is sulphonated, phosphorylated, carboxylated, quaternary-aminoalkylated or

Case 11/1

chloromethylated, and optionally further modified to yield - $\text{CH}_2\text{PO}_3\text{H}_2$, - $\text{CH}_2\text{NR}_3^{2+}$ where R^{20} is an alkyl, or - $\text{CH}_2\text{NAr}_3^{+}$ where Ar^x is an aromatic (arene), to provide a cation or anion exchange membrane. Further still, the aromatic moiety may

5 contain a hydroxyl group which can be readily elaborated by existing methods to generate - OSO_3H and - OPO_3H_2 cationic exchange sites on the polymer. Ion exchange sites of the type stated may be provided as described in WO95/08581.

10 Preferably, said polymeric material is sulphonated. Preferably, the only ion-exchange sites of said polymeric material are sites which are sulphonated.

References to sulphonation include a reference to

15 substitution with a group - SO_3M wherein M stands for one or more elements selected with due consideration to ionic valencies from the following group: H, NR_4^{2+} , in which R^y stands for H, $\text{C}_1\text{-C}_4$ alkyl, or an alkali or alkaline earth metal or a metal of sub-group 8, preferably H, NR_4^+ , Na, K,

20 Ca, Mg, Fe, and Pt. Preferably M represents H. Sulphonation of the type stated may be provided as described in WO96/29360.

Said polymeric material may include more than one different

25 type of repeat unit of formula I; more than one different type of repeat unit of formula II; and more than one different type of repeat unit of formula III.

Said moieties I, II and III are suitably repeat units. In

30 the polymeric material, units I, II and/or III are suitably bonded to one another - that is, with no other atoms or groups being bonded between units I, II, and III.

Case 11/1

Where the phenyl moieties in units I, II or III are optionally substituted, they may be optionally substituted by one or more halogen, especially fluorine and chlorine, atoms or alkyl, cycloalkyl or phenyl groups. Preferred 5 alkyl groups are C₁₋₁₀, especially C₁₋₄, alkyl groups. Preferred cycloalkyl groups include cyclohexyl and multicyclic groups, for example adamantyl. In some cases, the optional substituents may be used in the cross-linking 10 of the polymer. For example, hydrocarbon optional substituents may be functionalised, for example sulphonated, to allow a cross-linking reaction to take place. Preferably, said phenyl moieties are unsubstituted.

Another group of optional substituents of the phenyl 15 moieties in units I, II or III include alkyls, halogens, C_yF_{2y+1} where y is an integer greater than zero, O-R^q (where R^q is selected from the group consisting of alkyls, perfluoralkyls and aryls), CF=CF₂, CN, NO₂ and OH. Trifluormethylated phenyl moieties may be preferred in some 20 circumstances.

Where said polymeric material is cross-linked, it is suitably cross-linked so as to improve its properties as a polymer electrolyte membrane, for example to reduce its 25 swellability in water. Any suitable means may be used to effect cross-linking. For example, where E represents a sulphur atom, cross-linking between polymer chains may be effected via sulphur atoms on respective chains. Alternatively, said polymer may be cross-linked via 30 sulphonamide bridges as described in US 5 561 202. A further alternative is to effect cross-linking as described in EP-A-0008895.

Case 11/1

Where w and/or z is/are greater than zero, the respective phenylene moieties may independently have 1,4- or 1,3-linkages to the other moieties in the repeat units of formulae II and/or III. Preferably, said phenylene moieties have 1,4-linkages.

Preferably, the polymeric chain of the first material does not include a -S- moiety. Preferably, G represents a direct link.

10

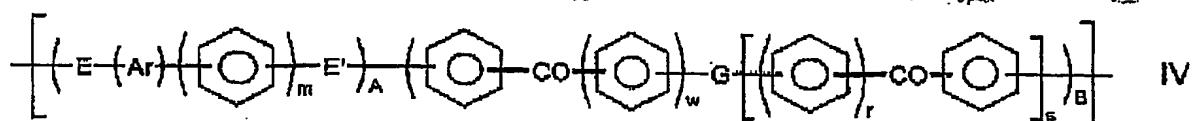
Suitably, "a" represents the mole % of units of formula I in said polymeric material, suitably wherein each unit I is the same; "b" represents the mole % of units of formula II in said material, suitably wherein each unit II is the same; and "c" represents the mole % of units of formula III in said material, suitably wherein each unit III is the same. Preferably, a is in the range 45-100, more preferably in the range 45-55, especially in the range 48-52. Preferably, the sum of b and c is in the range 0-55, more preferably in the range 45-55, especially in the range 48-52. Preferably, the ratio of a to the sum of b and c is in the range 0.9 to 1.1 and, more preferably, is about 1. Suitably, the sum of a, b and c is at least 90, preferably at least 95, more preferably at least 99, especially about 100. Preferably, said polymeric material consists essentially of moieties I, II and/or III.

Said polymeric material may be a homopolymer having a repeat unit of general formula

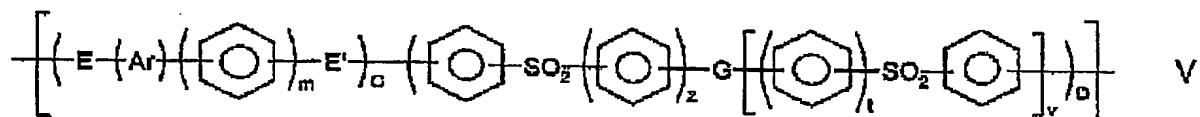
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Case II/1



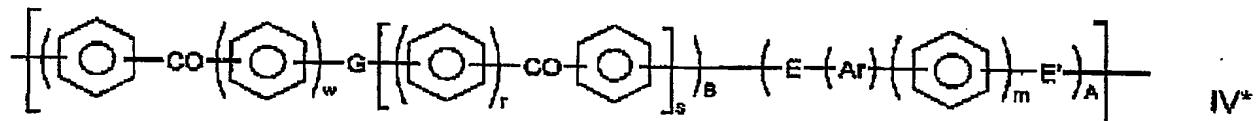
or a homopolymer having a repeat unit of general formula



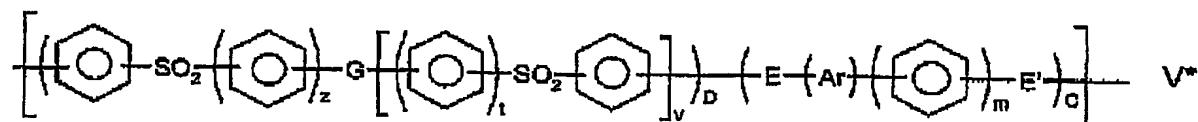
or a random or block copolymer of at least two different units of IV and/or V provided that repeat units (or parts
5 of repeat unit) are functionalised to provide ion-exchange sites;

wherein A, B, C and D independently represent 0 or 1 and
E, E', G, Ar, m, r, s, t, v, w and z are as described in any
10 statement herein.

As an alternative to a polymer comprising units IV and/or V discussed above, said polymeric material may be a homopolymer having a repeat unit of general formula



15 or a homopolymer having a repeat unit of general formula



or a random or block copolymer of at least two different units of IV* and/or V* provided that repeat units (or parts of repeat units) are functionalised to provide ion-exchange

Case 11/1

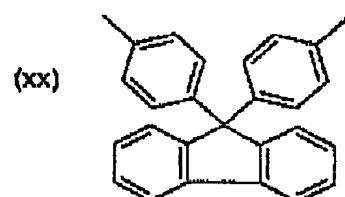
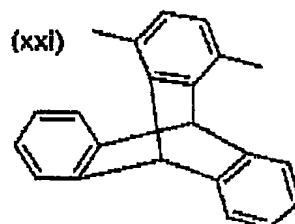
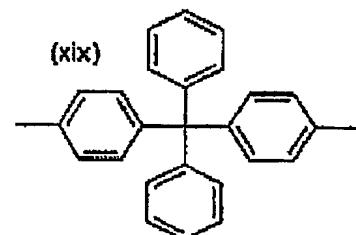
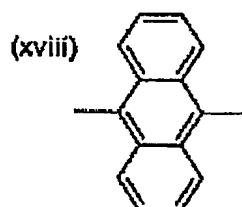
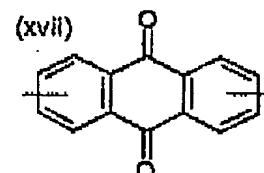
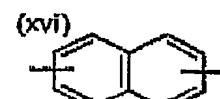
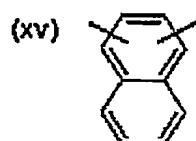
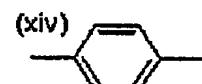
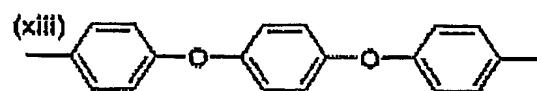
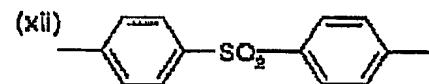
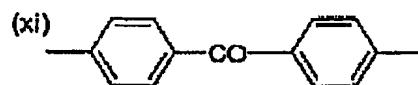
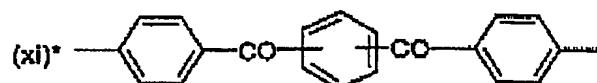
sites; wherein A, B, C, and D independently represent 0 or 1 and E, E', G, Ar, m, r, s, t, v, w and z are as described in any statement herein.

5 Preferably, m is in the range 0-3, more preferably 0-2, especially 0-1. Preferably, r is in the range 0-3, more preferably 0-2, especially 0-1. Preferably t is in the range 0-3, more preferably 0-2, especially 0-1. Preferably, s is 0 or 1. Preferably v is 0 or 1.
10 Preferably, w is 0 or 1. Preferably z is 0 or 1.

Preferably Ar is selected from the following moieties (xi)* and (xi) to (xxi):

15

Case 11/1



In (xi)*, the middle phenyl may be 1,4- or 1,3-substituted.

Case 11/1

Preferably, (xv) is selected from a 1,2-, 1,3-, or a 1,5-moiety; (xvi) is selected from a 1,6-, 2,3-, 2,6- or a 2,7-moiety; and (xvii) is selected from a 1,2-, 1,4-, 1,5-, 1,8- or a 2,6- moiety.

5

Unless otherwise stated in this specification, a reference to a crystalline material extends to any material having at least some crystallinity.

- 10 The existence and/or extent of crystallinity in a polymer is preferably measured by wide angle X-ray diffraction, for example as described by Blundell and Osborn (Polymer 24, 953, 1983). Alternatively, Differential Scanning Calorimetry (DSC) could be used to assess crystallinity.
- 15 The level of crystallinity in said polymeric material may be 0% (e.g. where the material is amorphous or crystallisable); or the level of crystallinity may be at least 0.5%, suitably at least 1%, preferably at least 5% weight fraction, suitably when measured as described by
- 20 Blundell and Osborn. The level of crystallinity in said polymeric material may be less than 20%.

Suitable moieties Ar are moieties (i)*, (i), (ii), (iv) and (v) and, of these, moieties (i)*, (i), (ii) and (iv) are preferred. Preferred moieties Ar are moieties (xi)*, (xi), (xii), (xiv), (xv) and (xvi) and, of these, moieties (xi)*, (xi), (xii) and (xiv) are especially preferred. Another preferred moiety is moiety (v), especially, moiety (xvi). In relation, in particular to the alternative first

- 25 polymeric materials comprising units IV* and/or V*, preferred Ar moieties are (v) and, especially, (xvi).
- 30

Case 11/1

One preferred class of polymeric materials may include at least some ketone moieties in the polymeric chain. In such a preferred class, the polymer preferably does not only include -O- and -SO₂- moieties between aryl (or other 5 unsaturated) moieties in the polymeric chain. Thus, in this case, suitably, a polymer of the first aspect does not consist only of moieties of formula III, but also includes moieties of formula I and/or II.

10 Preferred polymeric materials include -ether-biphenyl-ether-phenyl-ketone- units. Preferred polymeric materials may additionally include -ether-phenyl-sulphone-phenyl-ether-phenyl-ketone- units. Optionally, preferred polymeric materials may include -ether-phenyl-sulphone-15 phenyl-ether-phenyl-ketone- units.

Where a phenyl group is sulphonated, it may be mono-sulphonated.

20 The glass transition temperature (T_g) of said ion-conducting polymeric material may be at least 144°C, suitably at least 150°C, preferably at least 154°C, more preferably at least 160°C, especially at least 164°C. In some cases, the T_g may be at least 170°C, or at least 190°C 25 or greater than 250°C or even 300°C.

Said polymeric material may have an inherent viscosity (IV) of at least 0.1, suitably at least 0.3, preferably at least 0.4, more preferably at least 0.6, especially at least 0.7 30 (which corresponds to a reduced viscosity (RV) of least 0.8) wherein RV is measured at 25°C on a solution of the polymer in concentrated sulphuric acid of density 1.84gcm⁻³, said solution containing 1g of polymer per 100cm⁻³ of

Case 11/1

solution. IV is measured at 25°C on a solution of polymer in concentrated sulphuric acid of density 1.84g/cm³, said solution containing 0.1g of polymer per 100cm³ of solution. The measurements of both RV and IV both suitably employ a 5 viscometer having a solvent flow time of approximately 2 minutes.

The equivalent weight (EW) of said ion-conductive polymeric material is preferably less than 850g/mol, more preferably 10 less than 800g/mol, especially less than 750g/mol. The EW may be greater than 300, 400 or 500 g/mol.

The boiling water uptake of ion-conductive polymeric material measured as described hereinafter is suitably less 15 than 350%, preferably less than 300%, more preferably less than 250%.

The main peak of the melting endotherm (T_m) for said first polymeric material may be at least 300°C.

20 According to a second aspect of the invention, there is provided a polymeric material containing formulation (hereinafter "said pmc formulation") which comprises an ion-conducting polymeric material dissolved and/or 25 dispersed in a solvent formulation wherein;

(a) said ion-conducting polymeric material includes:
30 (i) phenyl moieties;
(ii) carbonyl and/or sulphone moieties; and
(iii) ether and/or thioether moieties; and

(b) greater than 50 wt% of said solvent formulation is made up of water.

Suitably, at least 55 wt%, preferably at least 60 wt%, of said solvent formulation is made up of water. In embodiments wherein a second organic solvent is included 5 in said solvent mixture, said pmc formulation may include a second organic solvent as described above. Said solvent formulation of said second aspect may include 0-40 wt% of said second solvent formulation. In preferred embodiments at least 95 wt%, especially at least 99 wt% of said 10 solvent formulation of the second aspect is made up of water. In especially preferred embodiments, said solvent formulation consists essentially of water.

Said pmc formulation may include at least 1 wt%, suitably 15 at least 3 wt%, preferably at least 7 wt%, more preferably at least 9 wt% of said ion-conducting polymeric material (or if more than one type of polymeric material is included, the total amount of polymeric materials may be as aforesaid). In some situations, said pmc formulation 20 may include greater than 30 wt%, or even greater than 40 wt% of said polymeric material(s).

The pmc formulation is preferably a stable solution/dispersion - that is, the polymeric material does 25 not substantially precipitate over time.

According to a third aspect of the present invention, there is provided a method of fabricating an article, the method including the step of contacting a member with a 30 formulation according to the first or second aspects. The method may be used to deposit the polymeric material on said member. For example, said member may be a support which may be contacted with said formulation in order to

Case 11/1

prepare a membrane; or said support may be coated with said formulation and/or said ion-conducting polymeric material in order to prepare an article which comprises said member and a coating prepared as described.

5

The method of the third aspect may be used in fabricating a wide range of types of articles. In one embodiment, said formulation may be used to impregnate a said member, for example a fibre or fabric. In this event, said solvent mixture may not include a said second organic solvent as described above. In another embodiment, said formulation may be used to form a film in which case, said solvent mixture may include a said second organic solvent. In either case, the method may be advantageous since said solvent mixture includes a major amount of water, rather than a major amount of organic solvent and is consequently easier to handle. Furthermore, it is found that a formulation according to the first or second aspects may include a relatively high concentration of said polymeric material (eg greater than 50 wt%) and, therefore, removal of solvents from the formulation after contact with said member may require less energy.

Any feature of any aspect of any invention or embodiment described herein may be combined with any feature of any aspect of any other invention or embodiment described herein mutatis mutandis.

Specific embodiments of the invention will now be described, by way of example, with reference to figure 1 which is a schematic representation of a polymer electrolyte membrane fuel cell.

Example 1a

A 700ml flanged flask fitted with a ground glass Quickfit lid, stirrer/stirrer guide, nitrogen inlet and outlet was charged with 4,4'-difluorobenzophenone (89.03g, 0.408 mole, mole ratio = 1.02), 4,4'-dihydroxybiphenyl (24.83g, 0.133 mole, mole ratio = 0.33), 4,4'-dihydroxydiphenylsulphone (53.65g, 0.213 mole, mole ratio = 0.536), 4,4'-dihydroxybenzophenone (11.37g, 0.053 mole, mole ratio = 0.134) and diphenylsulphone (332g) and purged with nitrogen for over 1 hour. The contents were then heated under a nitrogen blanket to between 140 and 150°C to form an almost colourless solution. While maintaining a nitrogen blanket, dried sodium carbonate (43.24g, 0.408 mole) was added. The temperature was raised gradually to 320°C over 3 hours then maintained for 1.5 hours.

The reaction mixture was allowed to cool, milled and washed with acetone and water. The resulting polymer was dried in an air oven at 120°C. The polymer had a melt viscosity at 400°C, 1000sec^{-1} of 0.34 kNsm $^{-2}$.

Example 2a

25

A 700ml flanged flask fitted with a ground glass Quickfit lid, stirrer/stirrer guide, nitrogen inlet and outlet was charged with 4,4'-difluorobenzophenone (89.03g, 0.408 mole, mole ratio = 1.02), 4,4'-dihydroxybiphenyl, (24.93g, 0.133 mole, mole ratio = 0.33), 4,4'-dihydroxydiphenylsulphone (66.73g, 0.267 mole, mole ratio = 0.67) and diphenylsulphone (332g) and purged with nitrogen for over 1 hour. The contents were then heated

Case 11/1

under a nitrogen blanket to between 140 and 150°C to form an almost colourless solution. While maintaining a nitrogen blanket, dried sodium carbonate (42.44g, 0.40 mole) and potassium carbonate (1.11g, 0.008 mole) were 5 added. The temperature was raised gradually to 315°C over 3 hours then maintained for 0.5 hours.

The reaction mixture was allowed to cool, milled and washed with acetone and water. The resulting polymer was 10 dried in an air oven at 120°C. The polymer had a melt viscosity at 400°C, 1000sec⁻¹ of 0.28 KNsm⁻².

By processes analogous to Examples 1a and 2a, further materials were prepared. A summary of the examples 15 including mole ratios used in the preparations and Melt viscosities (MV) achieved are provided in Table A below, wherein the following abbreviations are used:

BDF	4,4'-difluorobenzophenone
BP	4,4'-dihydroxybiphenyl
DHB	4,4'-dihydroxybenzophenone
Bis-S	4,4'-dihydroxydiphenylsulphone

TABLE A

25

Polymer	Polymer Composition (mole ratio)				MV KNsm ⁻²
	BDF	BP	DHB	Bis-S	
1a	1.02	0.33	0.134	0.536	0.34
1b	1.02	0.33	0.134	0.536	0.61
2a	1.02	0.33	-	0.67	0.28
2b	1.02	0.33	-	0.67	0.40

Example 3 - Sulphonation of polymers

The polymers of Examples 1 and 2 were sulphonated by stirring each polymer in 98% sulphuric acid (3.84g 5 polymer/100g sulphuric acid) for 21 hours at 50°C. Thereafter, the reaction solution was allowed to drip into stirred deionised water. Sulphonated polymer precipitated as free-flowing beads. Recovery was by filtration, followed by washing with deionised water until the pH was 10 neutral and subsequent drying. In general, titration confirmed that 100 mole% of the biphenyl units had sulphonated, giving one sulphonic acid group, ortho to the ether linkage, on each of the two aromatic rings comprising the biphenyl unit.

15

Example 4 - Membrane fabrication using NMP

Membranes were produced from the polymers of Examples 1 and 2 after sulphonation as described in Example 3 by 20 dissolution of the sulphonated polymers in NMP (N-methylpyrrolidone) to form homogenous solutions, casting the solutions onto clear glass plates followed by drawing down, using a Gardner knife, to give 400 micron films. The NMP was then evaporated.

25

Example 5 - Boiling Water Uptake

The following general procedure was followed to determine the Boiling Water Uptake of the membranes prepared.

30

5cm x 5cm samples of membranes were selected. The thickness of the samples was related to the concentration of polymers in the solvent systems used to cast the

Case 11/1

membranes. The membranes were separately immersed in boiling deionised water (500ml) for 60 mins, removed and dried quickly with lint-free paper to remove surface water, weighed, dried in an oven at 50°C for 1 day, 5 allowed to cool to ambient temperature in a desiccator then weighed quickly. The % water-uptake was calculated as described below:

$$10 \quad \% \text{ Water-uptake} = \frac{\text{Wet Weight} - \text{Dry Weight}}{\text{Dry Weight}} \times 100$$

Table B below provides results for the polymers of Examples 1 and 2 when fabricated as described in Example 4. EW refers to the "equivalent weight".

15

TABLE B

Sulphonated Polymer from	EW Theoretical	EW Actual	Boiling Water Uptake (%)
1a	683	677	143
1b	683	683	128
2a	690	694	140
2b	690	699	144

20 Example 6 - Membrane fabrication using water-based solvent formulations

Membranes were produced as described in Example 4, except that the sulphonated polymers were dissolved in a 50:50 mixture of acetone/water including 5 wt% NMP, at a sulphonated polymer concentration of 10 wt%. Dissolution may be undertaken at any temperature between ambient temperature and the boiling point of the solvent mixture. The falling ball viscosity of the above solutions was

Case 11/1

measured at 23°C using a Gilmont (Trade Mark) Instruments Falling Ball Viscometer using a stainless steel ball. Results for each solution, together with values for the boiling water uptake, measured as described in Example 5, 5 are provided in Table C below.

TABLE C

Sulphonated Polymer from	Falling Ball Viscosity (cP)	Boiling Water Uptake (%)
1a	892	106
1b	1227	102
2a	174	140
2b	417	147

10

Example 7 - Preparation of dispersions of sulphonated polymers in water and membrane fabrication

Example 7(a)

15

The sulphonated polymers were each dissolved in a 50:50 mixture of acetone and water and, subsequently, the acetone was removed using a rotary evaporator under reduced pressure (20mm Hg/40°C), leaving approximately 20 20 wt% sulphonated polymer in water. The formulation produced is probably not a true solution but is more likely a very fine dispersion of the sulphonated polymer in water. The dispersions had very low viscosities and membranes cast therefrom tended to be brittle. However, 25 the formulations could be used to impregnate fibres or fabrics and this may be facilitated by their low viscosities. Table D details the viscosity "before evaporation" for the formulations.

Example 7(b)

The procedure of Example 7(a) was followed except that, after removal of the acetone, some of the water was removed by using a rotary evaporator (20mm Hg/70°C) to produce more concentrated solutions (up to 50 wt% of sulphonated polymer in water). The formulation could be used to produce membranes. Table D details the viscosity of the formulations "after evaporation" of water, together with the "final concentration" of sulphonated polymer.

TABLE D

Sulphonated polymer from	Falling ball viscosity (cP)		Final conc. of sulphonated polymer (% w/w)
	Before evaporation	After evaporation	
1a	82	282	36
1b	23	314	49
2a	18	480	54
2b	21	680	53

Example 7(c)

The procedure of Example 7(b) was followed, except that a coalescing agent (NMP or ethylene glycol) was added as detailed in Table E to facilitate preparation of membranes. Membranes were prepared and boiling water uptakes (%) determined as described above. Results are provided in Table E below.

TABLE E

Sulphonated Polymer from	EW Theoretical	EW Actual	Amount NMP (wt%)	Final conc. of sulphonated polymer (%w/w)	Boiling Water Uptake (%)
1a	683	691	10	32	106
1b	683	701	15	42	102
2a	690	710	15	46	135
2b	690	709	15	45	158

5 It should be appreciated from Table E that no increase in EW is observed, suggesting the procedure described does not cause a loss of sulphonic acid groups.

Example 8 - Membrane fabrication using water-based solvent formulations

Membranes were produced as described in Example 4, except that the sulphonated polymers were dissolved in a 50:50 mixture of THF/water including 5 wt% NMP, at a sulphonated polymer concentration of 10 wt%. The values for the boiling water uptake measured as described in Example 5, are provided in Table F below. The falling ball viscosity of the above solutions were measured at 23°C using a Gilmont® Instruments Falling Ball Viscometer using a stainless steel ball.

TABLE F

Sulphonated Polymer from	Falling Ball Viscosity (cp)	Boiling Water Uptake (%)
1a	1034	109
2a	4964	136

Case 11/1

Example 9 Preparation of dispersions of sulphonated polymers in water and membrane fabrication

Example 9(a)

5

The sulphonated polymers were each dissolved in a 50:50 mixture of THF and water and, subsequently, the THF was removed using a rotary evaporator under reduced pressure (20mm Hg/40°C), leaving approximately 17 wt% sulphonated polymer in water. The formulation produced is probably not a true solution but is more likely a very fine dispersion of the sulphonated polymer in water. The dispersion had very low viscosity and membranes cast therefrom tended to be brittle. The aqueous solutions/dispersions could be used to impregnate fibres of fabrics. Table G details the viscosity "before evaporation" for the formulations.

Example 9 (b)

20

The procedure of Example 9(a) was followed except that, after removal of the THF, some of the water was removed by using a rotary evaporator (20mm Hg/70°C) to produce more concentrated solutions. The formulation could be used to produce membranes. Table G details the viscosity of the formulations "after evaporation" of water, together with the concentration of sulphonated polymer.

TABLE G

Sulphonated polymer from	Falling ball viscosity (cP)		Sulphonated polymer conc. (% w/w)
	Before evaporation	After evaporation	
1a	50	104	22
2a	800	1068	21

5 Example 9(c)

The procedure of Example 9(b) was followed, except that a coalescing agent (NMP or ethylene glycol) was added to facilitate preparation of membranes. Membranes were 10 prepared and boiling water uptakes (%) determined as described above. Results are provided in Table H below.

Table H

Sulphonated Polymer from	Boiling Water Uptake (%)	Final Sulphonated Polymer conc. (% w/w)
1b	98	20.9
2a	123	20

15

Attention is directed to all papers and documents which are filed concurrently with or previous to this specification in connection with this application and 20 which are open to public inspection with this specification, and the contents of all such papers and documents are incorporated herein by reference.

All of the features disclosed in this specification 25 (including any accompanying claims, abstract and drawings), and/or all of the steps of any method or

Case 11/1

~~process so disclosed, may be combined in any combination, except combinations where at least some of such features and/or steps are mutually exclusive.~~

5 Each feature disclosed in this specification (including any accompanying claims, abstract and drawings) may be replaced by alternative features serving the same, equivalent or similar purpose, unless expressly stated otherwise. Thus, unless expressly stated otherwise, each
10 feature disclosed is one example only of a generic series of equivalent or similar features.

The invention is not restricted to the details of the foregoing embodiment(s). The invention extends to any
15 novel one, or any novel combination, of the features disclosed in this specification (including any accompanying claims, abstract and drawings), or to any novel one, or any novel combination, of the steps of any method or process so disclosed.

7/1

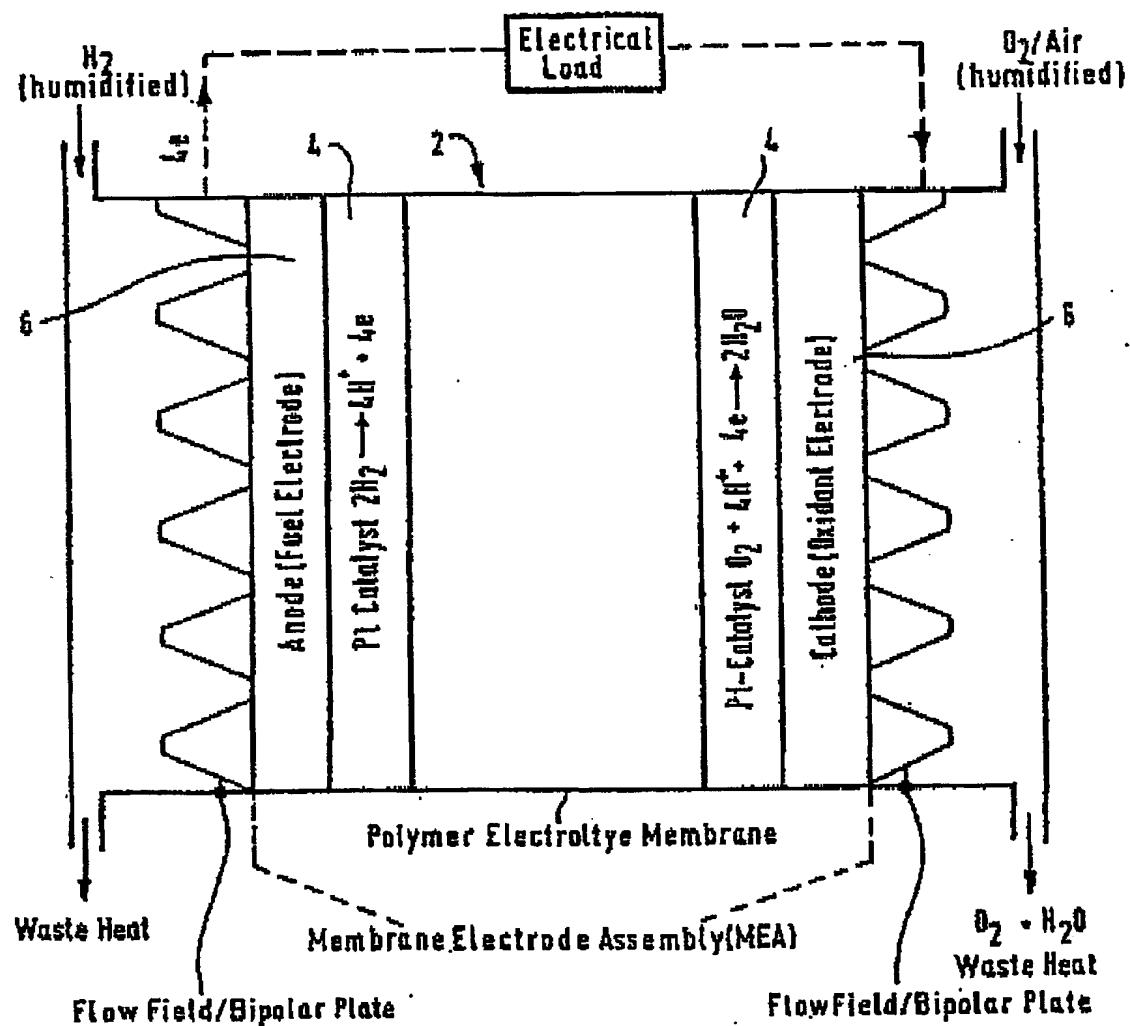


FIG.1.

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